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LOW ELEVATION ANGLE KU-BAND SATELLITE MEASUREMENTS AT AUSTIN, TEXAS

Wolfhard J. Vogel, Geoffrey W. Torrence, Murali Ranganathan*

Electrical Engineering Research Laboratory
The University of Texas at Austin
10100 Burnet Rd., Austin, TX, 78758

Abstract--At low elevation angles, the propagation of satellite signals is affected by precipitation as well as by inhomogeneities of the refractive index. Whereas precipitation causes fades for relatively small percentages of time, the refractive index variability causes scintillations which can be observed for most of the time. An experiment is now under way in Austin, Texas, in which the right-hand circularly polarized 12 GHz beacon of INTELSAT-V/F10 is observed at a 5.8 degree elevation angle, along with the radiometric sky temperature, the rainfall rate, humidity, pressure, temperature, and wind speed and direction. The objective of these measurements is to accumulate a database over a period of 2 years and to analyze the probabilities and dynamical behavior of the signal variations in relation to the meteorological parameters. This paper describes the hardware and software used for the data acquisition and analysis and presents results from the first year of measurements.

1. Introduction

Line of sight satellite communications links to earth operating at wavelengths shorter than 3 cm are subject to degradation brought about by the interaction of electromagnetic waves with some of the constituents of the troposphere. The most basic effect is the attenuation of the signal. Energy is removed from the wave either by absorption or redirection. At the frequency of interest here, 12 GHz, absorption is caused all of the time and at a relatively constant small rate by oxygen and water vapor and for a small fraction of the time and at large rates by rain or other hydrometeors. The second loss mechanism, redirection, is mainly associated with the time-varying inhomogeneities of the refractive index. The received power undergoes variations, because the phase front of the wave has been distorted or redirected. This effect is enhanced on paths with elevation angles below about 10 deg, where it occurs most of the time.

The objective of this research project is to make continuous measurements of the signal amplitude received from a

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*Now with Electro-Mechanics Co., Austin, Texas

satellite at 5.8 deg elevation and to correlate these data with simultaneously collected radiometric sky temperatures as well as local meteorological quantities. The motivation for the effort arises from the desire to utilize existing or new satellites to provide service to locations with elevation angles below current standards. In order to do this, however, the performance statistics underlying the service have to first be known or made predictable.

Many measurements have been performed on paths with elevation angles greater than 15 deg and prediction models developed for rain attenuation [CCIR, Rep. 721-2] and clear-air scintillations [CCIR, Rep. 718-2] are available. More recent measurements on low elevation angle paths have been summarized by Karasawa, Yamada, and Allnutt [1988], who proposed a new scintillation prediction technique incorporating meteorological parameters. The data obtained in this experiment will be used to further refine low elevation angle rain attenuation and scintillation models.

2. Experiment Description

Both the 11.198 GHz beacon receiver as well as the radiometer make use of the same 2.4 m conical horn-reflector antenna, employing opposite sense circular polarizations. The antenna's apex protrudes into a temperature controlled building, where it feeds the front-end electronics. Following down-conversion, intermediate frequency signals are sent to the back-end of the receivers and the data acquisition system, located directly below the antenna.

The beacon receiver is not of phase-locked loop design, but utilizes a 32 channel filterbank. The filters have a bandwidth of 100 Hz and are spaced at 50 Hz intervals.[Dinn and Zimmerman, 1978] The data acquisition program adjusts a synthesizer to track the satellite beacon within a particular filter. This design assures that the receiver measures fades to the noise threshold without data loss due to loss of lock conditions or lock acquisition delays. Samples of beacon data with low and normal scintillations and from a rain event are given in Figure 1.

The radiometer is of continuously calibrating, gain controlled, Dicke-switched design, implemented in a desk-top computer. It has three states, switching between (1) the antenna, (2) a computer controlled comparison load, and (3) the comparison load plus a noise source. The gain of the radiometer is adjusted to keep the output voltage during the third phase at a constant level. The radiometer's temperature to voltage conversion gain and noise temperature are monitored and used to calculate the measured sky temperature. The coupling of the antenna to the ground has been estimated to be 4 K. This estimate is based on comparing sky temperatures measured in clear air with calculations using the CCIR [Rep. 718-2] procedure.

Meteorological parameters measured at the site are the ambient temperature, pressure, relative humidity, wind speed, and wind direction. A tipping bucket rain gauge is used to measure rainfall rates.

All data are recorded by a desk-top computer based data acquisition system. The beacon level is recorded twice a second or every 10 seconds, depending on its variability and level; the sky temperature and meteorological quantities are recorded every 10 seconds.

3 Data Analysis Procedures

3.1 Quality Control

The raw data of each month go through a quality control inspection procedure. This consists of an interactive but highly automated program, displaying each hour's data graphically and allowing the operator to make appropriate editing decisions for abnormal conditions. The decisions are recorded in an ASCII file as a macro command, to be executed again by the data analysis program, when it expands the unedited raw data into calibrated and corrected time series of .5 second beacon samples and 10 second samples of all other quantities. Most of the exceptions are handled automatically by the quality control program, but full operator control is always available. The program also calculates 6 minute averages of the fade level and sky temperature, values used for the determination of the free-space and clear-air levels, as explained below. At each stage of these procedures, ASCII data files can be produced for plotting of any of the intermediate results.

The abnormal or exceptional conditions for which a macro entry is produced include any condition which is not the fast recording mode with all systems fully operational. Some of these conditions are the calibration periods, solar transit, and receiver malfunctions.

3.2 Clear-Air Level Estimation

The 6 minute averages for the beacon fade and the sky temperature calculated during the quality control pass of the data are recorded and used for the estimation of the free-space and the clear-air fade levels. The free-space fade level is the average signal fade relative to a level without any gaseous absorption and without antenna misalignment or receiver offset drift. As the gaseous absorption is about 1 dB at Ku band at 5.8 deg elevation, the normal free-space fade level is about 1 dB. The clear-air level is taken relative to this prevailing gaseous attenuation, i.e. the normal clear-air fade level is 0 dB.

The free space fade level for each 6 minute interval of a particular day is estimated using data including the three days

immediately before and after the day in question. Only data for which the sky temperature is less than 90 K are considered in the procedure. This avoids including rain fade events into the estimation. After subtracting from the beacon level the gaseous attenuation calculated from the measured sky temperature, only effects due to antenna misalignment and gain offsets remain. The 7 days of data are then subjected to a diurnal decomposition, which reveals both the moving average and the seasonal component.

Shown in Figure 2 for 25 days, the seasonal component has a 24 hour period and typically about 1 dB peak-to-peak deviation, because the receiving antenna is fixed but the satellite apparent azimuth and elevation are changing due to the motion of the spacecraft (.25 deg). A sidereal shift is noticeable.

The beacon fade levels are corrected with the smoothed diurnal variation estimates and the moving averages. The clear-air gaseous absorption estimate for each day is based on the lower quartile of the sky temperature derived attenuation, excluding fade events. The error of this estimate is probably of the order of .1 dB.

4. Results

The cumulative distribution of the beacon signal has been plotted (Fig. 3) on a logarithmic percentage scale. The solid curve represents the attenuation. The dashed curve, the enhancements, is derived from 100% minus the percentage the attenuation exceeded the ordinate. In April 1989 fades exceeded 16.7 dB and enhancements 2.5 dB for 0.1% of the time. The asymmetry of the plot is due to rain fades.

Slant path-length for typical water vapor content of 10 to 20 g/m^3 in Austin is about 10 airmasses or 25 km [Altshuler, 1986] at 5.8 deg elevation. Considerable signal level variations result in clear and cloudy turbulent air. As shown in Fig. 4, at a 0.1% probability level, the rms scintillations exceeded 4.7 dB in April 1989. This compares to below 2.0 dB for Dec. 1988, the most quiet month of the year.

Estimating the physical temperature from a regression analysis of the path transmission, defined by $10^{(-F/10)}$ with F the fade in dB, and the radiometric sky temperature resulted in 271.3 K for June 1988, based on equal probability values. Even though a single aperture is used for the two measurements, beam-filling effects, scintillations, as well as vertical temperature gradients can cause wide variations of the instantaneous value. This is demonstrated in Fig. 5, which shows an event which started with a temperature of 284 K. When the storm receded, the measured medium temperature dropped to only 239 K. Nevertheless, Fig. 6 shows that a median linear relationship between sky temperature and beacon transmission can be established. For April 1989, the dashed lines give event count contours (10 sec

samples) and the dotted curves are the 10th, 50th and 90th cumulative percentiles of the events.

5. Summary

A long term low elevation angle beacon experiment is now under way in Austin, Texas at Ku band. The effects of turbulence and rain will be measured and used to predict the performance of such links at other locations. While radiometers are invaluable to establish the clear air signal level, results point out the difficulty of estimating slant path fades other than averages from radiometric measurements, especially at low elevation angles, where the dynamic behavior of the channel is important.

6. Acknowledgements

The authors appreciate the superb construction of the filterbank by G. A. Zimmerman and H. J. Bergmann at BTL in the days of COMSTAR.

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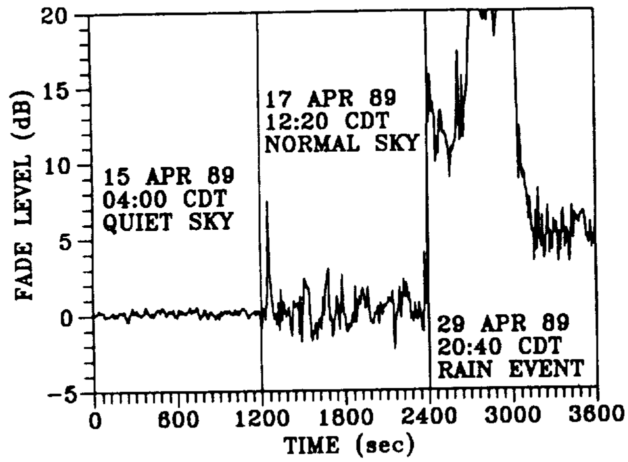

Fig. 1. Examples of beacon data with varying conditions

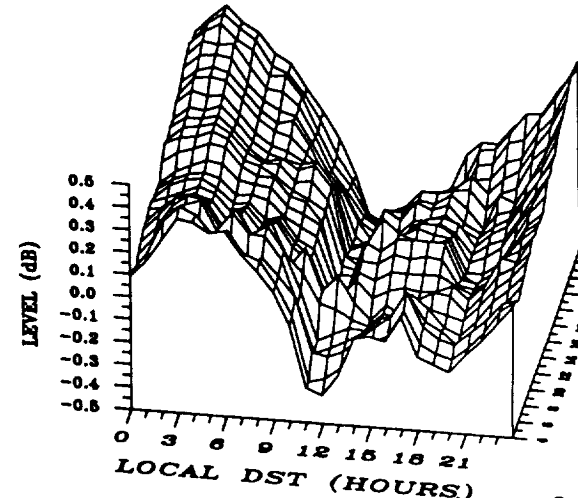

Fig. 2. Diurnal variation of the beacon level

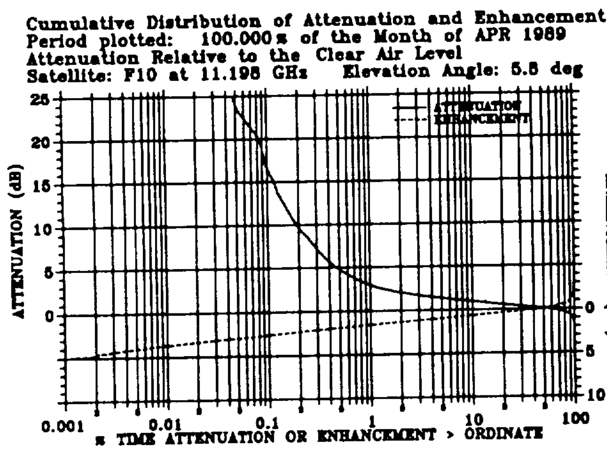

Fig. 3. Fade and enhancement distribution, Apr. 1989

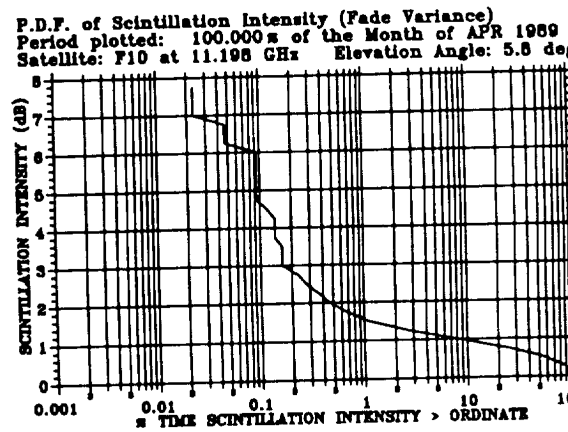

Fig. 4. Fade variance for Apr. 1989

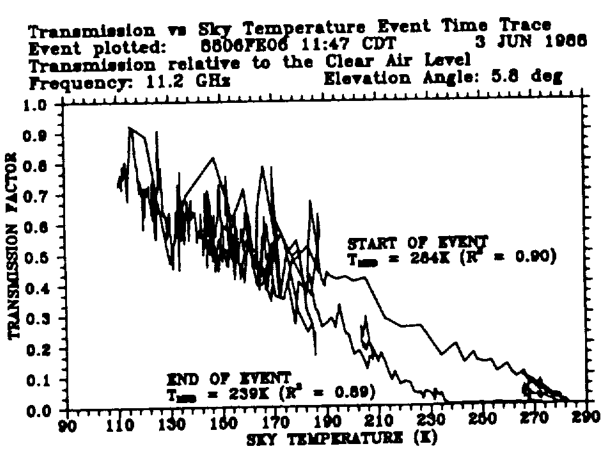

Fig. 5. An event trace for beacon transmission and the sky temperature

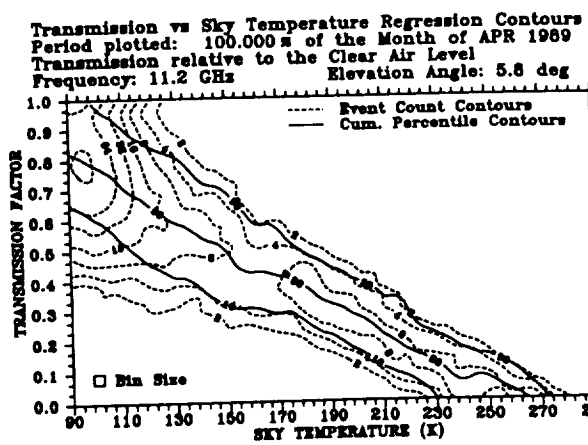

Fig. 6. Transmission factor vs. sky temperature regression contours